BLAST WAVE MITIGATION BY WATER

Philippe Chabin[1] and Franck Pitiot[2]
Groupe SNPE
Rue Lavoisier – B.P.2 – 91710 Vert-le-Petit – France

ABSTRACT

Safety systems designed to mitigate blast wave effects are absolutely vital in the explosives industry. As a general rule, barricades made of soil, sand or concrete are used, but these systems cannot be moved once they have been constructed. Since plants or installations are frequently required to change location the concept of a mobile barricade is of considerable interest.

The effect of a water wall on blast wave mitigation was studied in scale model tests. The influence of different parameters such as the thickness of the wall and the distance between the explosive charge and the water barricade was also calculated. This methodology enabled the use of nomographs giving excess pressure (overpressure) as a function of wall thickness, charge/wall distance and charge/location distance. The results showed the effectiveness of the water wall and confirmed its interest.

This study was carried out by performing tests in a reduced scale model plant. The purpose of the tests was to:

- *Confirm the effect of the weight of the water wall on far-field blast mitigation.*
- *Measure the effect of the water wall with regard to reflected pressures on rigid walls. In these cases water walls were created in front of the rigid walls.*

1.Introduction

This paper describes work carried out by SNPE on water wall mitigation of blast waves

Our approach to this work was essentially practical and involved the performance of many small-scale model tests.
The final goal of the tests was:
- to determine the size of a full scale water wall required in a plant,
- To quantify the mitigation of reflected pressures by the water wall,
- To measure the influence of water in far-field.

To achieve this goal, experiments with small-scale model tests were performed. These experiments were divided into unit tests (water and explosive charge only) and a more general test carried out using a small-scale model of a plant.

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[1] Detonics and safety laboratory
[2] Hazards and safety group

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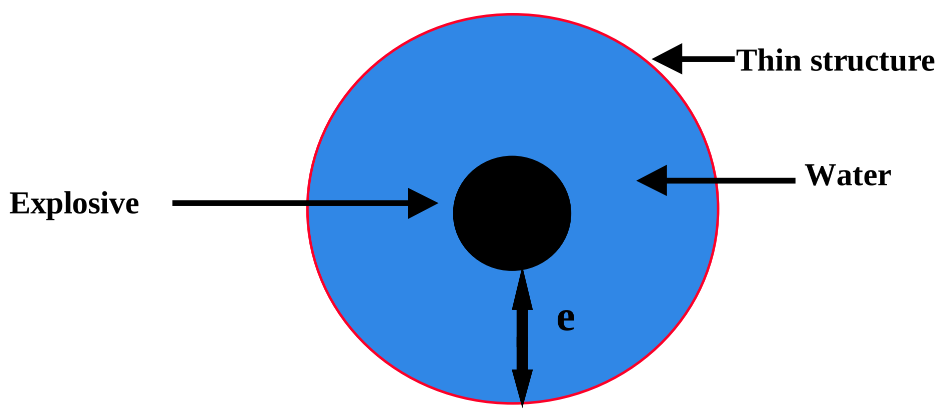
2.Experimental study

This study consisted of a test in three stages:

- Firstly, the effect of water in contact with explosives was observed and quantified,
- Secondly, parameters were positioned to determine the mitigation effect,
- Thirdly, a small-scale model of a plant was built in order to obtain a certain number of vital measurements (effect of the water barricade at long distance, effect of the water barricade on reflected pressures etc.).

2.1 Water in contact with the explosion

This was the first configuration tested by the SNPE. The explosive was placed inside a bag which was filled with water. The figure below shows the test:



The explosive which has been used in all the tests, is a french explosive named “Plastrite”.
The physical and chemical properties of this explosive are summarized in the table hereafter:

Composition	Density ρ (kg/m^3)	Detonation velocity D_{cj} (m/s)	Chapman Jouguet Pressure P_{CJ} (Gpa)
PETN 87%, Oil and gum: 13 %	1.42	7889	20.1

The first test concerned the ratio water weight/explosive weight.
The ratio (R) ranged from 0 to 50. Results for certain reduced distances are shown in the table below:

R	0	5	16,6	50
ΔP (Mpa)	0,175	0,14	0,12	0,065
$\overline{I^+}$ (Mpa.ms/kg$^{1/3}$)	0,1	0,075	0,08	0,08

These data written as percentages give the following values:

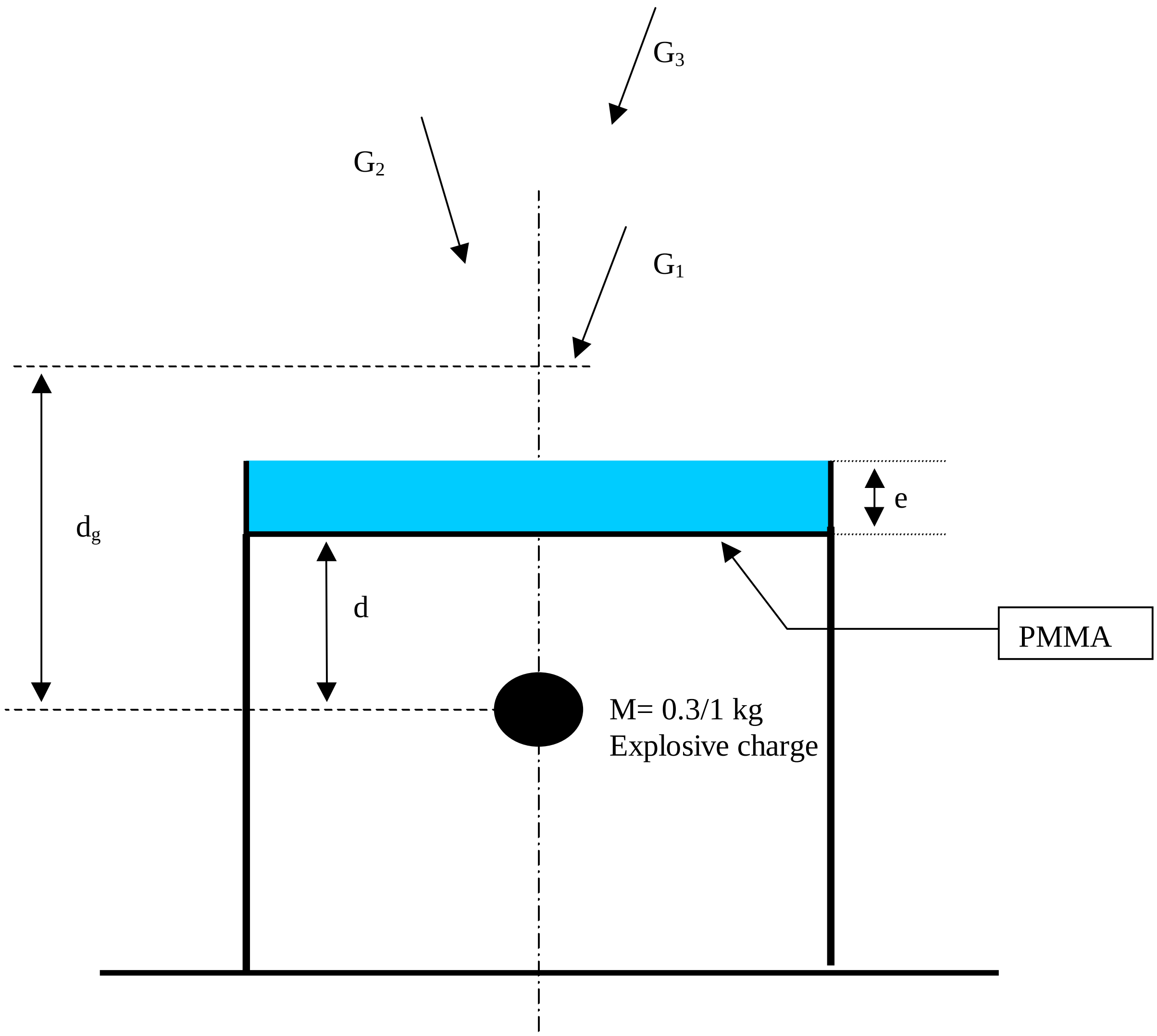
R	0	5	16,6	50
ΔP	100	80	69	37
$\overline{I^+}$	100	75	80	80

As the ratio increases, the overpressure decreases. However it was observed unfortunately that scaled impulse drops between ratio 0 to 5 and then remains level thereafter. There is no modification when the ratio increases.
This ratio remains effective (between 0 and 50) for the overpressure peak but with regard to the impulse the minimum is between 5 and 16. The results obtained are in the same range as the results obtained by S.Eriksson [3]

2.2.Water wall remote from explosive charge.

In general, although water can be used to surround explosives in ammunition stores, this will prove more difficult and sometimes impossible in industrial processes as personnel must be able to perform process operations. However, the buildings of the plant must still be protected.
A compromise must therefore be reached.
The second series of tests were performed with a water wall physically separated from the explosive charge.
The figure below shows the test configuration.

[3] FORT/F REPORT C 104. 4th symposium on the military applications of blast simulation. S.ERIKSSON. Souten-on-sea. 1974.



To study the effect of water wall not in contact with the explosive, it is necessary to minimize the resistance of structures (PMMA) used to retain the water. Consequently, the water wall was horizontal with a surface open to the air opposite the charge. Transformation into spray is facilitated by this configuration.
The following 3 parameters were tested in this experiment:

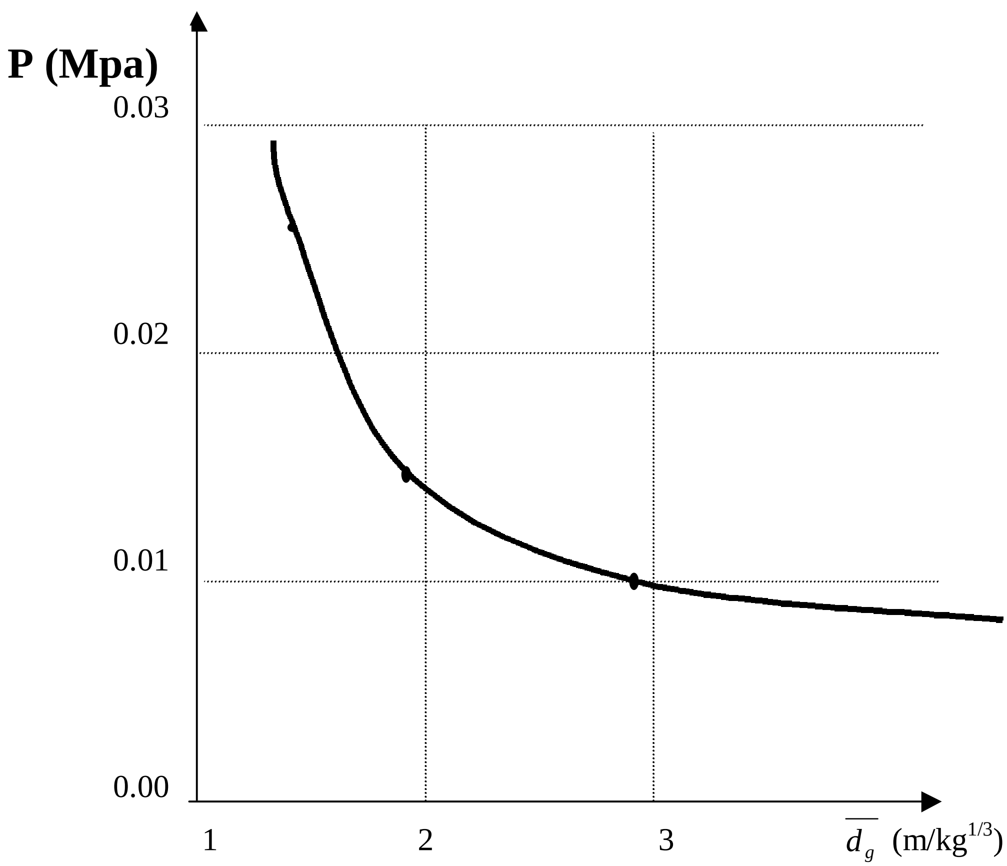
- $\overline{dg}$, the scaled distance between explosive and gauges,
- $\overline{e}$, the scaled thickness of water,
- $\overline{d}$, the scaled distance between explosive and water wall.

The ratio considered in the previous section cannot be used here because it is impossible to locate the wall all around the explosive. The blast wave is studied in a single direction and the water wall is located only in this zone.

The range of the three parameters is:

- $1{,}4 \leq \overline{dg} \leq 5$ (m/kg$^{1/3}$)
- $0 \leq \overline{d} \leq 1$ (m/kg$^{1/3}$)
- $0 \leq \overline{e} \leq 16.10^{-2}$ (m/kg$^{1/3}$)

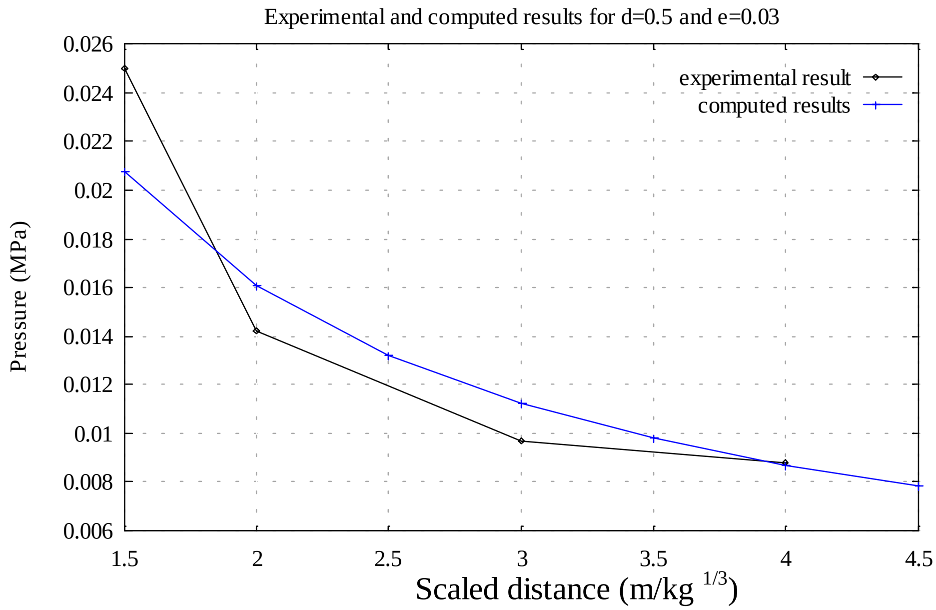
Sixteen shots were carried out in order to establish an empirical function which would enable the overpressure beyond the wall to be predicted using the 3 parameters above. To do so, all the results are plotted on a graph and are smoothed as drawn on the figure below.



These results provided a cluster of curves which were used to find the coefficients of an empirical overpressure law as follow:

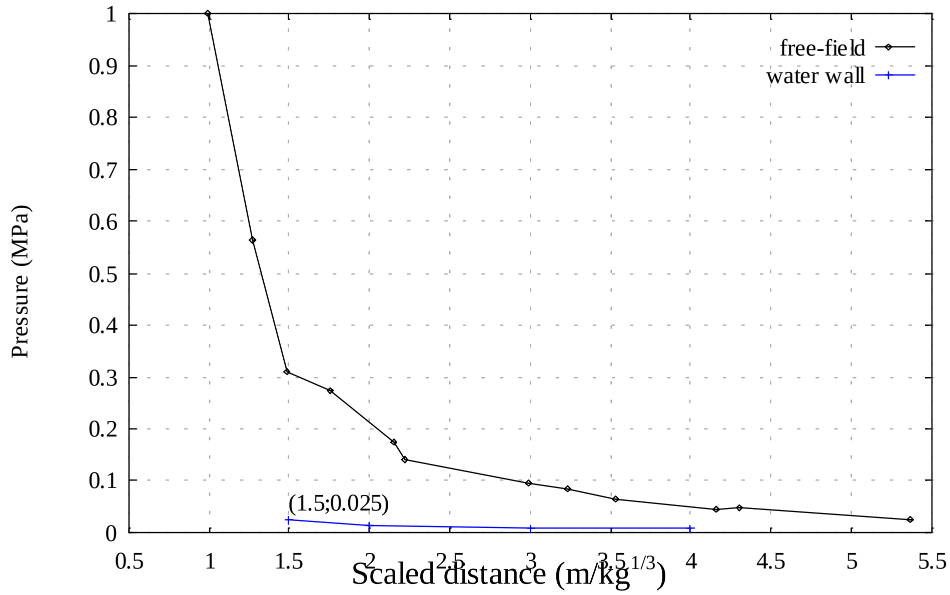
$$\Delta P = f(\overline{d_G}).g(\bar{e}).h(\bar{d})$$

This law is the product of three functions which have exponential and hyperbolic decay.
The computed and experimental curves for $\bar{d}$= 0,5 and $\bar{e}$= 0,03 are shown below.



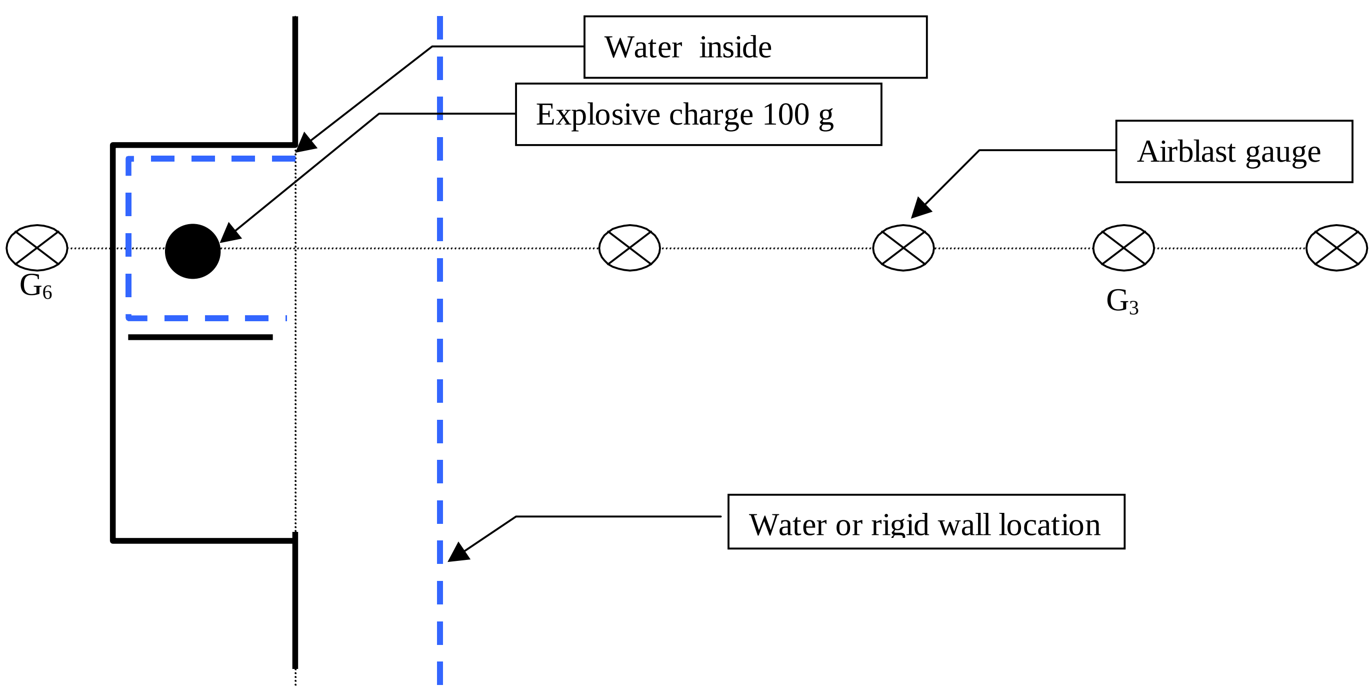
In these tests by far the most important parameter is the explosive/water distance (d).
On the one hand it was observed that if $\bar{d}$ increases by 80 %, ΔP decreases around 70 %, on the other hand if $\bar{e}$ increases of 150 %, ΔP decreases approximately 50 %. This is certainly because at the deepest limit, the water wall behaves like a rigid wall and fragmentation into droplets is more difficult.
The figure hereafter shows a comparison between a free-field explosion and behind a water wall mitigated explosion:

($\bar{d}$= 0.5 and $\bar{e}$= 0.03 m/kg $^{1/3}$)



3.Small-scale model building

A small-scale model of a normal plant building has been constructed.
It is a three wall building divided in two section as shown in the figure below.



plan view of generic test layout

This scaled model is built of steel and the walls are considered as completely rigid.
Some airblast gauges have been positioned at ground level to record the over pressure signal.
The aim of this test is to compare the long distance signal of pressure behind a steel barricade and a water wall.

One can think that with the water wall, the water droplets generated by the explosion would continue to disturb the progressive propagation of the blast wave. Similarly the spray may also serve to cool the hot gas bubble.
For these reasons the over pressure should be lower in this configuration.
Three main tests have been performed as follows:

- One test with a water wall in front of the explosive charge,
- One test with a rigid wall,
- One test with a water wall plus water inside the building.

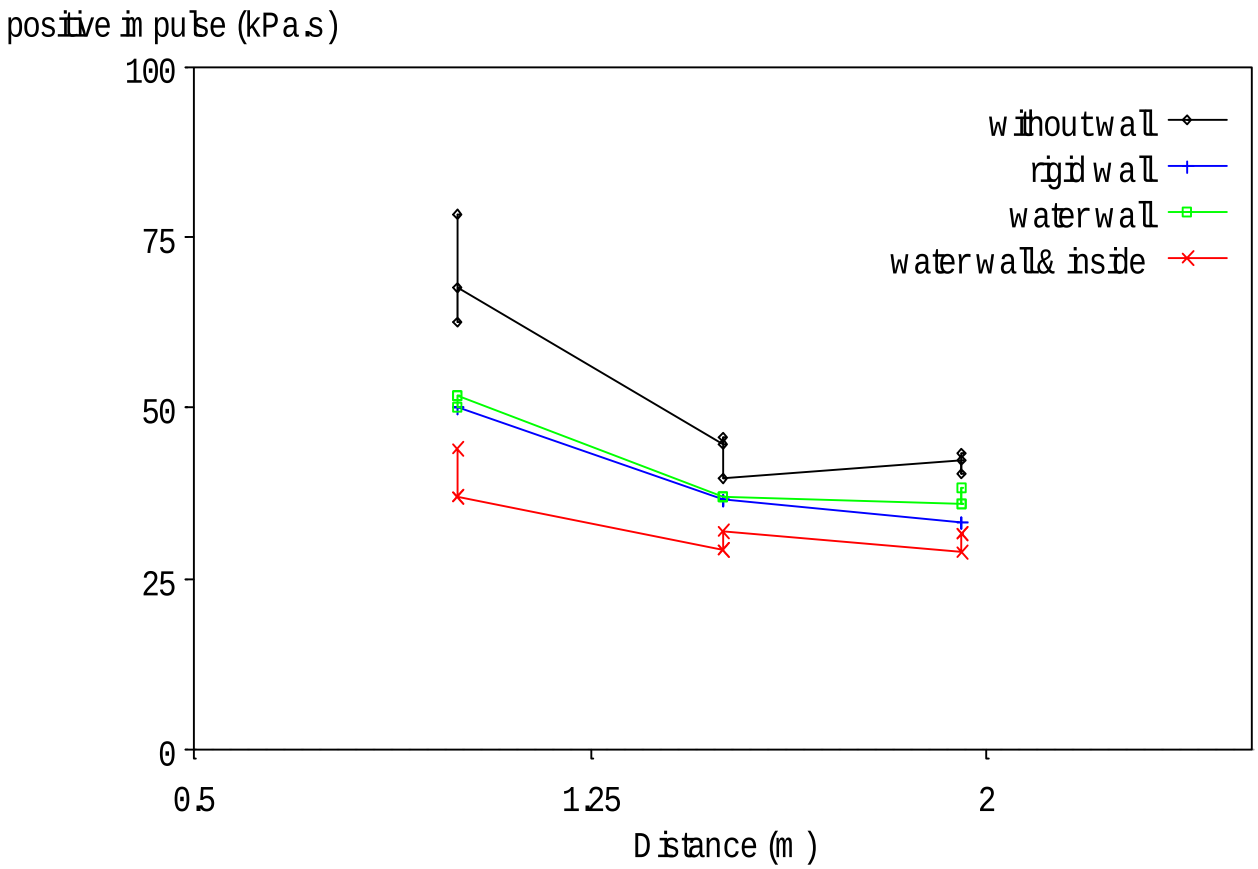
These small-scale tests allow to consider the effects of surroundings (walls, geometry…).

3.2.Principal trends.

In the far-field and outside the shadow zone (approximately four times the height of the wall), there was no difference between the overpressure behind the rigid wall and that behind the water wall. For example at 1.95 meters (gauge G_3), results of 78 kPa and 73 kPa respectively were obtained. The control test (without wall) gives at this distance an overpressure equal to 75 kPa.

It has been also observed that the rigid wall, reflects the shock wave in the opposite direction and increases the overpressure on the rear side. For example, the overpressure on G_6, at 1 meter is 58 kPa in the control test and 62 kPa with a water wall. We obtain 98 kPa with a rigid wall.
(i.e 80 % increase)

On the other hand the impulse is lower when water is used inside.
The graph hereafter plots the positive impulses with the different tests.



When water is placed inside the small-scale model (water to explosive ratio = 20) the overpressure becomes 60 kPa on G_6 and 69 kPa on G_3. This experiment shows that the use of water inside the building modifies the overpressure.

The table below summarized the overpressure results:

	Reference	Rigid wall	Water wall	Id.+ water inside
G_3	75 kPa	78 kPa	73 kPa	69 kPa
G_6	58 kPa	98 kPa	62 kPa	60 kPa

The water wall alone is as efficient as a rigid wall (and sometimes more) in the shadow area. In far-field the pressure level is the same. On the rear side the advantage between the water and the steel wall is the lack of reflected pressure. The water inside the building reduces the positive impulse.

4.Conclusion

Laboratory tests showed that the use of a water wall is effective.
The attenuation of blast wave is significant especially when the water wall is remote from the explosive charge.
It was shown that the reducing effect is dependent on:

- the water to charge-weight ratio,
- the charge/water distance and the thickness of water.

The gain on overpressure is between 20 to 80 % and around 20 % on scaled impulse

An empirical law giving the overpressure behind the wall has been obtained for a determined range of magnitudes (paragraph 2.2).
The results, obtained with the unit tests, has been completed by small-scale tests on model building.
It has been shown that, behind the wall in the shadow area, water wall is as effective as a rigid wall (and perhaps better). In a far-field it is the same mitigation. It is important to notice that on the rear side there is no reflected pressure contrary to rigid wall..
It is also important to notice that the positive impulse decreases when water is inside the small-scale model. This is of interest because this impulse (or the pressure signal) is used to calculate the resistance of a structure.

Water wall is a practical option (cheap, mobile…) to attenuate blast waves. They may be particularly useful when the plant structure cannot be modified, but it is necessary to take environment into account.

In an industrial application, it will be necessary to ascertain that the structure used to retain the water has:

- an impedance close to that of the water itself,
- no resistance (the structure must be easily shattered).
- Resistance to ultra-violet rays…

Acknowledgement

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We would like to express our gratitude for their thoroughness and diligence in the performance of this work.